# Defining and Implementing Best Available Science for Fisheries and Environmental Science, Policy, and Management

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In the United States, many of the laws governing environmental conservation and management stipulate that the best available science be used as the basis for policy and decision making. The Endangered Species Act, for example, requires that decisions on listing a species as threatened or endangered be made on the basis of the "best scientific and commercial data available." Similarly, National Standard 2 of the Magnuson-Stevens Fishery Conservation and Management Act states that conservation and management measures shall be based on "the best scientific information available." Further, the U.S. Environmental Protection Agency has emphasized the role of best available science in implementing the Clean Water Act (USEPA 1997). Determining what constitutes the best available science, however, is not straightforward, and scientists, policymakers, and stakeholders often have disparate ideas on how the concept should be defined and interpreted.

The American Fisheries Society and the Estuarine Research Federation established a committee to consider what determines the best available science and how it might be used to formulate natural resource policies and procedures. This synopsis examines how scientists and nonscientists perceive science, what factors affect the quality and use of science, and how changing technology and societal preferences influence the availability and application of science. Because the issues surrounding the definition of best available science surface when managers and policymakers interpret and use science, we also discuss the interface between science and policy and explore ways in which scientists, policymakers, and managers can more effectively apply science to environmental policy. The full report is available at www.fisheries.org.

## DEFINING BEST AVAILABLE SCIENCE

Science means different things to different people. Science may be viewed simply as a body of organized knowledge or as a rigorous, standardized way of collecting information. Science may be more broadly viewed as a way of knowing things or creating knowledge, where what is defined as knowledge is based on a mix of observation, intuition, experimentation, hypothesis testing, analysis, and prediction. Each of these views of science is valid. Each recognizes implicitly that multiple conceptions of science exist. Each is crucial to understanding the controversy associated with defining best available science. However, these subtle differences in how science is perceived can lead to major differences in how it is used to develop policies and implement management decisions.

Although most nonscientists recognize science as a source of information, many do not appreciate the range of scientific approaches or the importance of debate, dissent, skepticism, and personal opinion involved in the process of producing scientific knowledge. Interpretations of scientific findings by nonscientists range widely because of the many personal contexts and frames of reference that nonscientists have in relation to their understanding of science (Weber and Word 2001). Unfortunately, many policymakers, regulators, and judges have unrealistic expectations of science. They expect science to produce uncontested, value-free, universally applicable knowledge that is accessible to everyone, scientist and nonscientist alike (Salter 1988; Pouyat 1999). Although the scientific process is designed to minimize the influence of values, that influence can never be entirely eliminated. Nevertheless, adherence to a methodology that minimizes subjectivity throughout the process of knowledge development is perhaps the greatest distinction between the scientific and nonscientific arguments employed in support of policy decisions (Rykiel 2001).

Science provides a basis for measuring changes in the environment, for understanding how ecosystems operate, and for predicting how a change in environmental conditions might affect ecosystem operation. However, science cannot provide a basis for choosing human goals with respect to the management of these systems. Goal setting, an integral part of policymaking, is a value-based process. A common misconception of nonscientists is that science can provide objective answers to the thorny question, "How should we manage this ecosystem or resource?" Such questions can be answered only by reconciling the socially constructed values and expectations of the stakeholders at the policymaking table. Scientists may, of course, participate in goal setting, but they should neither be expected nor claim to be completely objective under those circumstances. In contrast, science can inform society about the consequences of its management goals and actions, which may lead to revised goals and actions, but goal setting itself is outside the realm of science.

## WHAT IS BEST SCIENCE?

### *Science and the Scientific Process*

To achieve high-quality science, scientists conduct their studies using what is known as the scientific process, which typically includes the following elements:

- A clear statement of objectives;
- A conceptual model, which is a framework for characterizing systems, making predictions, and testing hypotheses;
- A good experimental design and a standardized method for collecting data;
- Statistical rigor and sound logic for analysis and interpretation;
- Clear documentation of methods, results, and conclusions; and
- Peer review.

The first step in developing a research plan and ensuring the quality of the scientific process lies in a clear statement of objectives. Without such a statement, it is all too easy for procedures to be applied haphazardly and for results to be ambiguous. Once clear and relevant objectives have been posed, the next step is to develop a framework for prediction and testing hypotheses. In the context of management, formulating conceptual frameworks (models) should facilitate decision making. Conceptual models allow predictions to be made under alternative scenarios, while the possible consequences and risks are objectively explored.

Scientists recognize that the information coming out of an analysis is only as good as the information going into it. That is why the scientific community has set up standards for collecting information and ensuring data quality. Once the data are obtained, they are usually analyzed and interpreted in the context of some hypothesis being tested or some estimate or prediction being formulated. Models and hypotheses, however, are subject to a number of assumptions. Scientists should present results under alternative models or assumptions so that the range of reasonable interpretations is clearly stated. Scientists and policymakers together should identify relevant ecological or social processes, assumptions, and risks of falsely interpreting scientific results. Frank communication of the limitations of knowledge can promote respectful relations between scientists and policymakers (Bolin 1994). The failure of scientists to consistently articulate the limits of science has contributed to a recent erosion of public trust in scientific experts (Ludwig 2001). Sound science is characterized not so much by the reliability of the particular bits of knowledge produced as by the reliability of a transparent, repeatable scientific process.

A basic precept of science is that it must be verifiable. This is what separates science from other methods of understanding. However, direct verification is not always possible. In lieu of this, scientists review the results of scientific inquiry as a community to assess its validity. This is the process of peer review. The rigor of the peer review is one way to categorize the degree to which a scientific study is adequate for informing management decisions. To scientists, peer review is a formal process conducted by active, knowledgeable experts in the general field of the study of interest. The peer review covers:

1. The validity of the methods used,
2. Whether the methods and study design adequately address the objectives,
3. Whether the results that are reported are adequate for interpretation,
4. Whether the results support the conclusions, and
5. Whether the findings represent a significant advance in scientific knowledge.

Typically, several knowledgeable scientists conduct the review independently and anonymously.

While the scientific community is primarily interested in the validity of the research, the public and policymakers are more interested in the impact of science on societal decisions. Thus the basis for judging science differs, as does the meaning of valid evidence (Clark and Majone 1985). The policy implications of science are judged not only on the basis of its quality but also regarding how it influences the public. Science, as well as discussions of "best" science, becomes controversial to nonscientists only when it has the potential to change societal policy.

## SCIENCE AND HUMAN UNDERSTANDING

Science is a human endeavor. Consequently, it is limited by human abilities and influenced by human principles, beliefs, and values. Scientists attempt to deal with these limitations and influences by being open about them. Unfortunately, all knowledge is embedded in uncertainty. There are many sources of uncertainty and many frameworks in which to categorize that uncertainty (see Hilborn 1987; Suter et al. 1987; Wynne 1992; and Elith et al. 2002 for several frameworks germane to the aquatic sciences). Common sources of ecological uncertainty include:

1. Lack of basic biological information, exemplified through natural history or demographics;
2. Lack of information on functional relationships between populations and environmental factors;
3. Unpredictable events, such as the timing of floods and hurricanes; and
4. High variability associated with key parameter estimates (Mangel et al. 1996).

Scientists often deal explicitly with some types of uncertainty but largely ignore other types (Wynne 1992; Costanza 1993). Discussion of risk, that is, the expected loss associated with decisions made under uncertainty, is common in scientific discourse. New approaches that more openly acknowledge uncertainty are needed to implement socially acceptable safeguards against adverse effects. A key challenge is to develop scientific methods that estimate the social costs of uncertainty so that those costs can be distributed equitably across society (Costanza 1993).

There is renewed interest in the scientific community about ethics in conducting science (NRC 1995; Macrina 2000). The public perception that science is objective should be tempered by the fact that scientists are human and not immune to human imperfections. Although it is not always apparent, personal values are inseparable from the practice of science (Roebuck and Phifer 1999). Constitutive values shape all scientists' choices of what warrants studying, how to frame hypotheses, and which methods to apply (Shrader-Frechette and McCoy 1993; Franz 2001). Fisheries science has traditionally focused on stewardship and sustainability as principal underlying values (Smith 1994). Increasingly however, fisheries and environmental issues have attracted interest within the discipline of biological conservation, which is inescapably normative (Barry and Oelschlaeger 1996). Advocacy for preserving biological diversity is central to this and is based on the belief that biodiversity is intrinsically good (Soule 1985) and that naturally evolved elements of diversity such as genomes, communities, and landscapes are more valuable than artificial elements (Angermeier 2000). Moral obligations also come into play. The major revelations of ecology include the dependence of humans on other biota and the connectivity of the biosphere (Costanza et al. 1997). Thus, the ethics of environmental science encompass rules for considering the needs of non-human biota and future humans.

The unavoidable link between science and values presents two consequences for scientific recommendations regarding environmental policy. First, sound science must include explicit expression of underlying values, especially those values that may cause serious conflict (Barry and Oelschlaeger 1996; Allen et al. 2001). Second, stakeholders—and the scientists who support them—should participate in the debate leading to policy decisions (Dietz and Stern 1998; Ludwig 2001). Legitimate sources of technical disagreement among scientists sometimes adds confusion to the public debate. However, the debate itself often clarifies issues and determines many of the key questions that need to be addressed in the future. Forums should be sought for such public debate.

## WHAT IS BEST AVAILABLE SCIENCE?

Information is now available to scientists and the public through a wide variety of sources, including the World Wide Web and popular media. The conventionally accepted sources for scientific information are the peer-reviewed literature, the gray literature, expert opinion, and anecdotal experience. These sources are commonly viewed as reflecting different levels of innovation, quality, respectability, and accessibility depending on the source and the uses to which they have been put. However, it may not be possible to conclude that a single source of information—conventional or new—is the best under all circumstances.

Recognizing what knowledge is available per se is not especially contentious. It is the quality of that information that must be critically addressed. This concern should cause us to recall the criteria for best science: that is, that the questions be clearly stated, the investigation well designed, and the results analyzed logically, documented clearly, and subjected to peer review. Therefore, to have the best available science, scientists, policymakers, and the public should seek to have good science made more available so that the available science is of higher quality.

## POLITICAL FACTORS INFLUENCING BEST AVAILABLE SCIENCE

Many nonscientists and scientists believe that science is being increasingly politicized. Articles in newspapers (e.g., Broad and Glanz 2003) and professional newsletters document frequent instances in which the process and products of science are interfered with for political or ideological reasons. In these cases, the soundness of science, as judged by those interfering, turns on the extent to which the evidence supports a particular policy stance or goal. What was previously an objective scientific debate then becomes centered on values in a public forum. Some environmental sociologists refer to such a debate as a "tournament of values" (Hull and Robertson 2000). While public debate about science-informed issues is important, for we must identify values of concern and risks associated with alternative management actions, political intervention itself can be a major barrier to the sound practice and application of science.

Politicization comes from many sources, each influencing the process and results of science through a variety of strategies and ranges from adapting the evidence to support a specific policy position to manipulating the broader issues in ways that determine their priority in political agendas. Several recent publications (e.g., Hutchings et al. 1997; Wilkinson 1998; Trachtman and Perrucci 2000; Restani and Marzluff 2001) document a variety of politicizing strategies that affect three major components of the science-policy interface, namely: acquiring knowledge, communicating information, and incorporating knowledge into policy.

The acquisition of knowledge often appears to be less politicized than the other components of the science-policy interface. However, scientists can be inhibited from acquiring new knowledge through restrictions on data collection and funding opportunities (Boesch 1995), or by establishing unachievable standards for risk or certainty. The communication of scientific knowledge and the uncertainty attending it is often highly politicized. Common politicizing tactics include delaying or suppressing releases of reports, misrepresenting the scientific basis of findings, misrepresenting alternative hypotheses, suppressing or denouncing scientific dissent, downplaying selected uncertainties, and manipulating conclusions. Finally, scientific discourse is commonly influenced by controlling the productivity or use of science. For example, political interference can impair the ability of scientists to understand the problems and formulate solutions associated with fishery collapses (Hutchings et al. 1997).

## IMPLEMENTING BEST AVAILABLE SCIENCE

The preceding sections provide a practical framework for recognizing and developing the best available science while avoiding the politicization of science. How science gets implemented, however, ultimately rests on how well it is interpreted and conveyed through policy. Although scientists play an important role in implementing science, they rarely control the process. Furthermore, unpopular management decisions often lead to claims of "poor science" and calls for additional scientific review, which can obscure the substantial social conflicts at issue. We emphasize several points regarding the social complexity of incorporating science into policy:

- Science can be used to formulate clearer, less ambiguous laws and regulations;
- Natural resource and conservation issues are expanding beyond a single-species focus to include multispecies and ecosystem-level trade-offs. Scientific principles can be applied to ecosystem management to make it more effective with fewer surprises;
- Science and policy involve responsibility. Effective policymaking requires participants to recognize who is responsible for what and to apply precautionary (i.e., risk-averse) approaches when uncertainty is great and/or risks are onerous. This includes discussion of how risks are to be allocated among present and future stakeholders;
- Information relevant to policy comes from multiple sources and varies in its objectivity. Both scientific and value-based information are valuable, but they tend to inform different parts of policy development. As more stakeholders participate in the process of developing science-based policy, scientists will be increasingly challenged to influence management decisions and outcomes; and

- Science is only one part of a complex political process.

The prevalence of over-harvested aquifers, forests, and fish stocks, and of imperiled species, is testimony to the failure of policymakers to apply best available science. To enhance the likelihood that their science is properly implemented, scientists will need to become more familiar with and more engaged in the nonscientific aspects of policy development.

Scientists committed to the sustainable management of ecosystems are developing new strategies to buffer science from political interference, while keeping open the possibility for a democratic debate. These strategies fall into four main categories:

1. Invoke independent review by experts with little vested interest in outcomes of the review or the associated policy;
2. Develop standard procedures and criteria for decision making, before reaching decision points;
3. Revise bureaucracies to broadly integrate information but keep separate the scientific and policymaking functions; and
4. Promote scientific literacy among policymakers and the public, where literacy means not only being familiar with facts and technologies but also being able to think critically to reach an informed opinion on public issues.

We expect these strategies to become increasingly important to incorporating best available science into environmental policy. Furthermore, we believe that scientific societies (e.g, AFS) are more capable than individual scientists of advancing these strategies.

## CONCLUSIONS

The best available science can be defined and acquired for any resource or environmental issue, including the most controversial ones, so that fully informed decisions are possible. However, for this to take place it is essential that scientists, policymakers, and the public be aware of the factors affecting the development and limitations of science and its implementation.

The results of a sound scientific process need not be infallible to be the best available. Scientific information and the conclusions it supports will always be subject to multiple interpretations, but greater transparency in the process will go far in addressing skepticism and averting controversy. High-quality science adheres to the well-established scientific process. The soundness of any science is enhanced if associated values, assumptions, and uncertainties are clearly explained.

Science is a human endeavor. As such it is limited by human understanding of the systems we interact with and implicitly or explicitly is influenced by underlying human principles, values, and beliefs. Maintaining transparency and openness in the scientific process when communicating methods, assumptions, and findings may be difficult, but it should promote better science. Limits to human understanding are a primary source of uncertainty in scientific knowledge and of risks associated with management actions. Scientific debate is an important mechanism by which scientists can explore the consequences of uncertainty and risk for environmental decision making.

Unfortunately, even science that has been developed through an open, transparent, and well-communicated process may not be fully adequate for addressing management issues. Scientists must often rely on incomplete information in offering their best expert advice. That is why scientists are obligated to articulate the limits of science and develop means for overcoming problems in communicating sci-

scientific information, assessing uncertainty in predictions, and evaluating risk in decision making.

Scientific information and information about science-related subjects are available in different forms. The peer-reviewed literature is what scientists have traditionally considered the best scientific information, and until recently this form of information was also the most accessible. Changes in communication technology have increased the availability of other forms of information, such as gray literature and professional and public opinion. As these other forms of information become more available, it will be harder for nonscientists to distinguish high-quality information from low-quality information. Scientists will have to play a greater role in assisting the public and policymakers with sorting out objective information from highly biased opinion. Published scientific debate may be one means of doing this, but such forums may be misconstrued as being equivalent to independently peer-reviewed science. Clearly, scientists and publishers will have to be more attentive to how controversial and emerging science is communicated.

Because government agencies act both as representatives of the public interest and as scientific bodies, conflicts can arise as to how information is collected and utilized and how it is communicated. Agencies should acknowledge potential conflicts and move to ameliorate them whenever possible. Providing forums for public observation of the scientific process and public participation in scientific debates is one means of accomplishing this. Administrative separation of agency divisions tasked to conduct science and develop policy may also be an effective way to avoid clouding issues and to reduce conflicts of interest. However, policy and science groups should communicate closely to ensure that management decisions are informed by the best available science.

Resolution of many of today's environmental issues, such as the influence of human activities on ecosystems, is hampered not only by rudimentary scientific understanding available but also by a weakly developed scientific process. Most scientists have been reluctant to go beyond the safety zone of traditional scientific approaches, namely, hypothesis testing and statistical interpretation of results. Because management decisions continue to be made with whatever information is available, scientists need to become more involved in identifying information quality and providing guidance on how the available information might best be used.

To adequately implement the best available science, it is essential that policymakers clearly articulate the purpose of regulations and laws, clearly specify who is responsible for interpreting and enforcing them, endeavor to identify and reduce conflicts of interest, and recognize differences in the knowledge base and values of scientists, managers, and other stakeholders.

The public is becoming increasingly involved in the scientific process, thus leading to the democratization of science. Similarly, scientists are becoming more involved in the public arena, sometimes having greater influence on public policy but also becoming more susceptible to political influence. The greater level of information exchange among scientists, policymakers, and the public means that scientists need to improve their means of communication, both in terms of providing information to more nonscientists and in terms of obtaining and interpreting information from a broader array of sources.

We offer the following general recommendations to promote the use of best available science in fisheries and environmental management.

- Scientists, policymakers, and the public should become more familiar with the range of spatial and temporal scales, the types and levels of uncertainty, and the necessary suite of scientific disciplines associated with science-based solutions to today's environmental problems, and ensure that the most pressing information needs for decision making are met.
- Scientific professionals should do more to make good science widely recognized and available, invest more in establishing scientific literacy among nonscientists, and develop ways to more clearly communicate technical information to policymakers and the public.
- Scientific professionals should become more active in establishing broadly accepted criteria to distinguish sound science, to assess the quality of scientific information, to distinguish types and uses of "peer review," to define scientific debate, and to ensure that science is properly incorporated into policy.
- Resource management agencies should organize themselves so that scientific and regulatory arms are administratively independent, formally engage recognized advocates of best available science, and proactively guide democratization of the science relevant to agency missions.

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